A Housing Energy Management Program Report

Energy
Ontario

FINAL REPORT
ON THE
FIELD OPERATION OF A
RESIDENTIAL SPACE HEATING
AND COOLING SYSTEM

REPORT NO. 1C

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by

THE CONSUMERS' GAS COMPANY LTD.

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SUMMARY

During the 1981/1982 and 1982/1983 heating seasons, The Consumers' Gas Company Ltd. conducted a field evaluation on a new market entry appliance, a self-contained hybrid residential forced warm air space heating system; 50% of the funding for the project being provided by the Ministry of Municipal Affairs and Housing.

Two models of the space heating system were evaluated, one against a soft reference standing pilot natural gas furnace over the two heating season period, the other against a soft reference conventional oil fueled forced air furnace during the 1981/1982 heating season and against a hard reference electric plenum heater during the 1982/1983 heating season. The units were operated on a daily change-over basis alternating operation every 24 hours over the heating season.

The energy consumption of each appliance under test was recorded through metering and referenced to outside temperature at each site. The consumption data gathered for each appliance at each site was analyzed by a regression analysis against outside temperature and comparisons made on the correlations.

Analysis of the data show that the hybrid system has seasonal operating cost savings in the range of 5.5% - 7.0% ($27 - $29/yr) over a standing pilot conventional natural gas furnace. Cost savings of 32.8% ($331/yr) over a conventional oil-fueled warm air furnace and cost savings 20.6% ($179/yr) over an electric plenum heater were achieved, using gas, oil and electric rates of 21¢/m^3, 20.3¢/l, and 3.55¢/kW·h respectively during the

1981/1982 heating season when the hybrid units were tested against the oil and gas reference systems. Rates of 22.7¢/m^3 for gas and 3.83¢/kW·h were used in the 1982/1983 heating season, for comparison with the electric and gas systems.

Both units under test performed in a satisfactory manner over both of the evaluation periods with no homeowner complaints on performance and with little or no service requirements. External noise levels at about 68dBA, 1 m from the unit were satisfactory, but the indoor noise generated by the hybrid unit appeared higher (though still unobjectionable) than the conventional warm air furnaces.

1.0 INTRODUCTION

The Consumers' Gas Company Ltd. has an interest in the field performance, service characteristics and safety aspects of all new high efficiency, gas burning appliances which are introduced into the marketplace.

The Ontario Ministry of Municipal Affairs and Housing (MAH) also has an interest in newly introduced energy-saving appliances which could reduce significantly the energy consumption in the provincial housing stock.

As a result of the mutual interest, MAH and The Consumers' Gas Company Ltd. proceeded on a fifty/fifty joint-funding basis to field evaluate two models of a new style residential space conditioning system which has been designed, developed, manufactured and marketed in Canada.

An installation report entitled "Kool-Fire Home Comfort Control System Field Trials", and a second report entitled "Interim Report on the Field Operation of a Residential Space Heating and Cooling System", were published in the Fall, 1981, and the Spring, 1983, respectively.

This report covers the modifications recommended in the interim report, the analyses of the performance data gathered over the 1982/1983 heating season and includes, for completeness, the oil heating comparison from the 1981/1982 heating season.

The appliance under test is a self-contained hybrid heat pump system. The appliance is tested in the heating mode only; the cooling performance is not evaluated.

2.0 OBJECTIVE OF THE EVALUATION

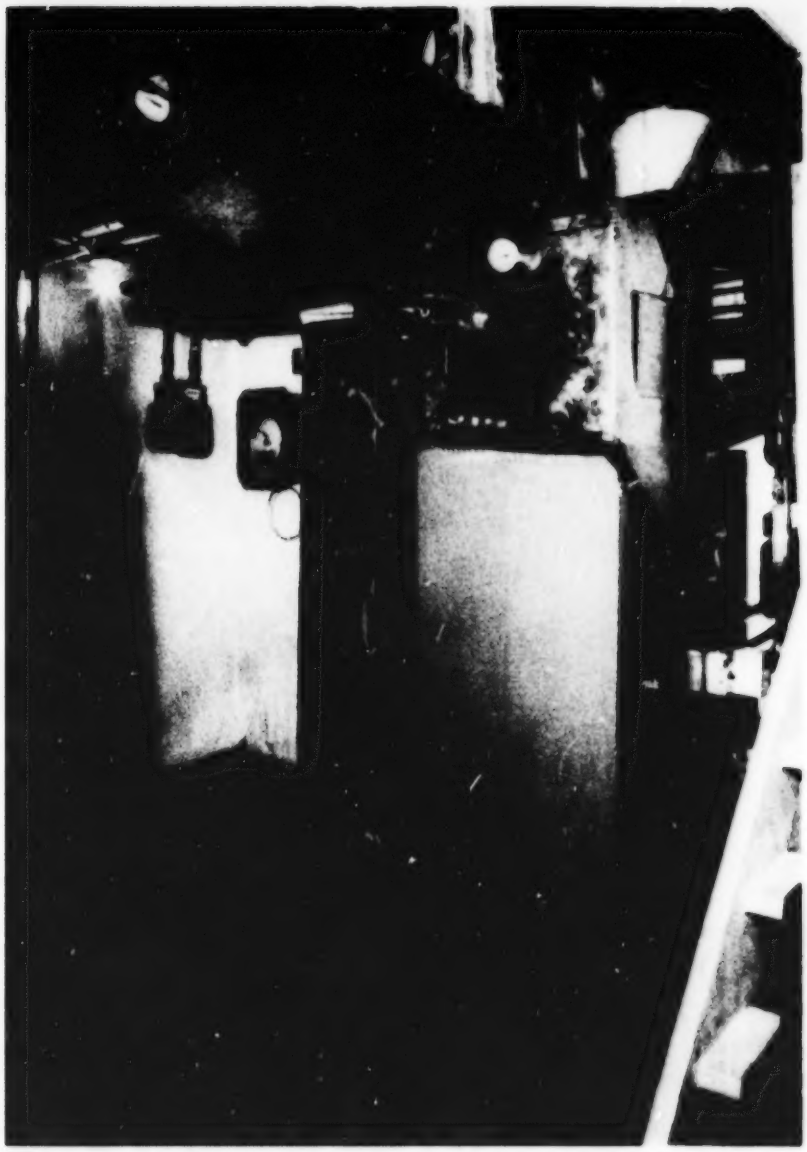
The objective of the evaluation is to ascertain the energy consumption and operating cost of the appliance and to compare that cost, in one instance to a conventional standing pilot gas-fired forced-air furnace, and in the other instance to an electric plenum heating system. The Interim Report on the Field Operation of a Residential Space Heating System, evaluated this system against a conventional oil fired forced-air furnace and a standing pilot gas-fired furnace. The salient results from the 1981/1982 interim report are included in this report for completeness.

3.0 DESCRIPTION OF SYSTEM UNDER TEST

Two models of the device are installed in two locations, one in Bowmanville, Ontario and the other in Willowdale, Ontario. During the 1982/83 heating season the unit at Bowmanville is tested against a conventional standing pilot, gas-fueld forced warm-air furnace, and the Willowdale unit is tested against an electric plenum heater.

The Bowmanville indoor installation is shown in Figure 1 and the Willowdale indoor installation is shown in Figure 2. The external unit, which is similar at both sites, is shown in Figure 3.

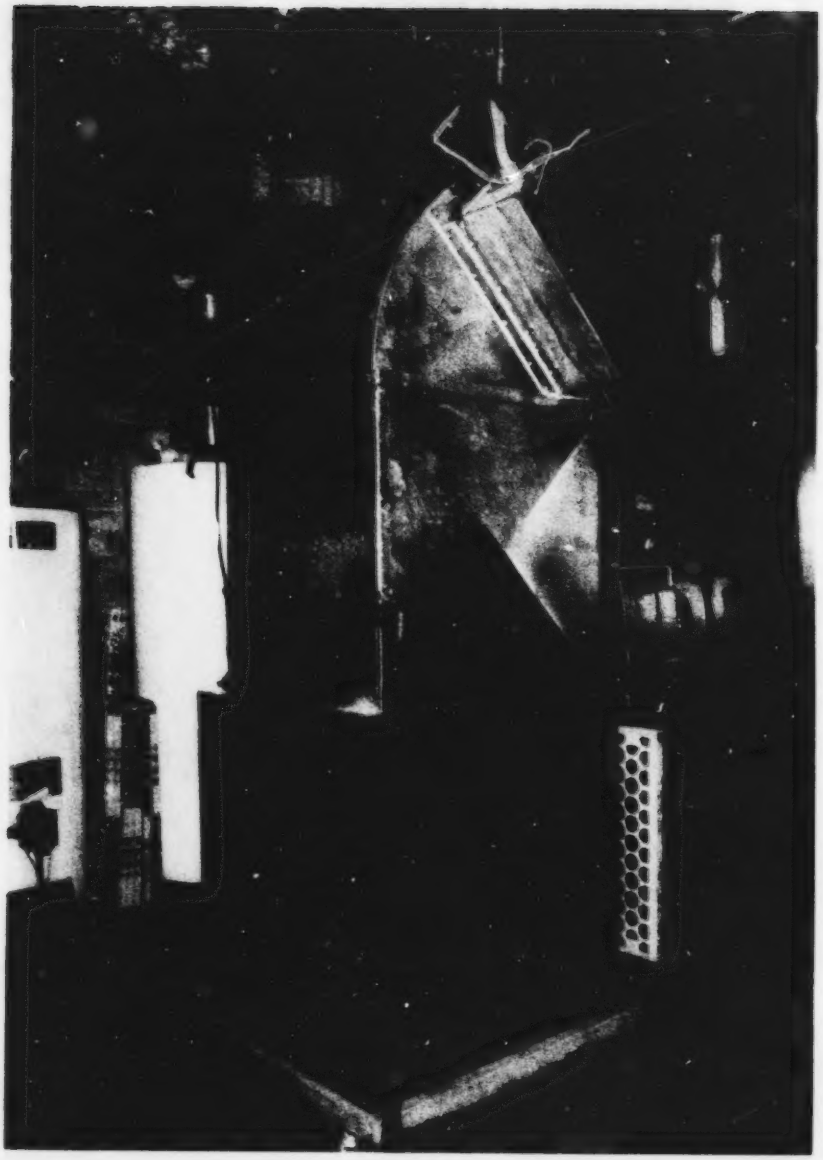
The device under evaluation and test is a space heating and cooling system which is, in effect, a hybrid heat pump. This device utilizes both electric energy and natural gas energy. It operates in exactly the same manner as a conventional electric heat pump down to an ambient temperature of about 9°C. At this temperature, the device switches automatically out of the heat pump mode into a high efficiency, condensing gas furnace mode.



BOWMANVILLE SITE INSTALLATION

INDOOR SECTION

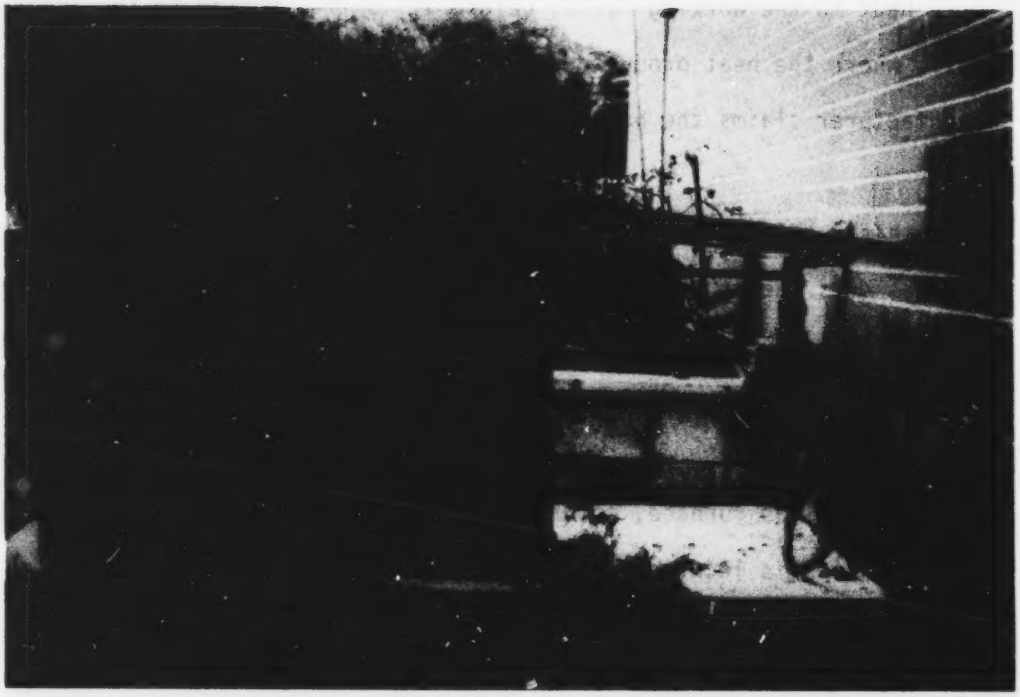
FIGURE 1



WILLOWDALE SITE INSTALLATION

INDOOR SECTION

FIGURE 2



OUTDOOR SECTION OF HYBRID

HEAT PUMP SYSTEM

FIGURE 3

The gas furnace consists of a gas burner located under the outdoor heat exchanger. When activated, the heat produced from the gas burner is transferred to the working fluid in the heat pump system, through the outdoor heat exchanger. In this condensing gas furnace mode the compressor in the unit continues to run, to provide both fluid circulation and to add more heat to the working fluid, before it is transferred to the indoor coil, where the heat produced outdoors is given up to the residence. The manufacturer claims the heat exchange in this mode is 98% efficient.

With this configuration the appliance requires no back-up or supplementary heat as does the conventional heat pump. In addition, no energy intensive defrost cycle is required with this unit as it changes modal operation before the ambient conditions causing frosting are reached.

The complete gas furnace, compressor and exterior coil are housed in a cabinet which is located outside the building (refer to Figure 3). As such, no chimney or conventional flue system is required.

The hybrid appliance at the Willowdale site delivers tempered air to the dwelling with an airflow rate of about 33 m^3/min. The combination of the lower grade heat and the higher airflow in the test device provides better air distribution in the home and appears to reduce stratification. The conventional gas-fired heating system blower, which is used as the soft reference monitor at the Bowmanville site, delivers air to the dwelling at an airflow rate of about 22.4 m^3/min.

Figure 4 is a descriptive schematic showing a typical conventional heating system and the configuration of the new system under test.

The basic system under evaluation is described more fully in the Installation and Interim Reports.

4.0 SITE READINGS AND RESULTS

4.1 Bowmanville

The installation at Bowmanville is unchanged from last season in that the performance of the new space heating system is being compared to the energy use and cost performance of the existing conventional natural gas fueled furnace. This evaluation is comparative only as the monitor is a soft reference, and the results do not provide data for calculating the seasonal efficiencies of either system.

Again, the systems were changed over on alternate days, with the conventional gas furnace being used as the soft monitor or control unit.

Readings are recorded daily on an alternate day basis and a table of the actual energy use incurred over the heating season for each system is provided in Table 1. The electrical consumption and gas consumption for the period of 108 days as outlined in Table 1 for the novel system being tested is 3 072 kW·h and 428 m^3 respectively. The

SCHEMATIC OF CONVENTIONAL SYSTEM AND SYSTEM UNDER TEST

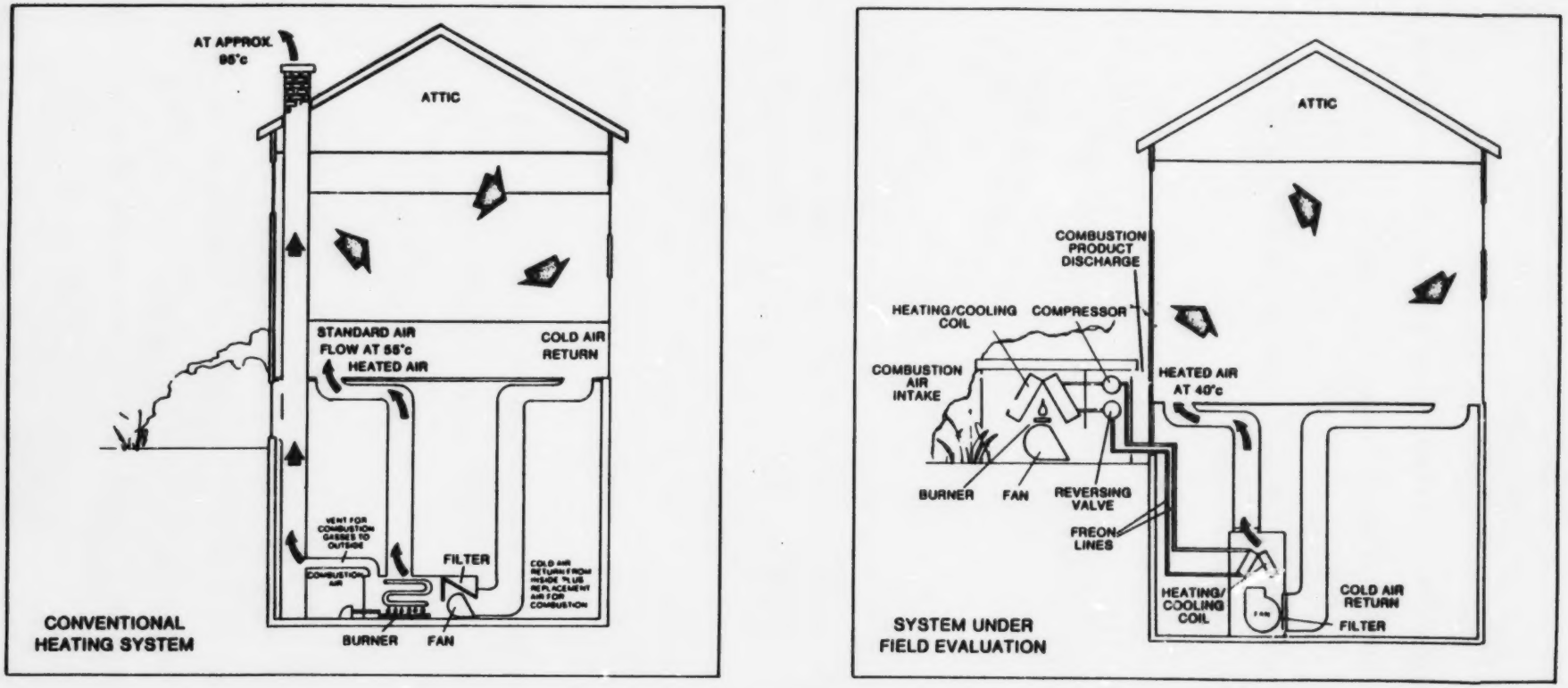


FIGURE 4

SUMMARY OF 1982/1983 ACTUAL HEATING CONSUMPTION

TABLE 1

BOWMANVILLE SITE

Month	Hybrid System			Gas Furnace		
	Electricity Consumption (kW·h)	Gas Consumption (m^3)	No. of Days Operating	Electricity Consumption (kW·h)	Gas Consumption (m^3)	No. of Days Operating
October	162	14.2	8	44	17.0	7
November	360	42.5	16	180	87.8	14
December	534	85.0	16	189	127.5	15
January	576	102.0	15	278	209.6	16
February	503	85.0	14	204	133.1	14
March	408	59.5	14	215	110.5	17
April	385	34.0	16	203	68.0	14
May	144	5.7	9	119	25.5	9
Total	3 072	427.8	108	1 432	779.0	106

consumption for the conventional gas control furnace (for the period of 106 days as outlined in Table 1) is 1 432 kW·h for the electricity consumed and 779 m^3 for the natural gas consumption.

The actual consumption data gathered from the site and shown by month (refer to Table 1) is used to draw the regression analysis graphs of daily energy consumption against daily mean temperature for each appliance. This is shown in Figures 5 and 6. The dotted line (Figure 5) represents the seasonal gas consumption and the solid line (Figure 5) represents the electric consumption from the hybrid unit being tested. Both lines have been drawn lineally and cut the x-axis at two different reference points. In reality, the electric consumption line would not cut the x-axis at the point shown as the unit would switch to total gas use at ambients of about 10°C and no external fan energy would be used. The regressed gas consumption line extension shows a reference point for the house at about 14°C. This is acceptable, but it could probably be higher because a linear regression has been used which forces the line through this point. In reality, it is suspected that this line may be curvelinear at the higher outdoor temperatures.

Figure 6 shows the linear regressions of the energy consumption for the soft reference gas furnace control unit. As expected, the electrical energy consumption is small and relatively constant throughout the period of the test. The regressed line cuts the abscissa at a temperature of approximately 16°C which is the reference point for this house. This point is higher than that obtained last year. The larger number and more consistent readings taken during the

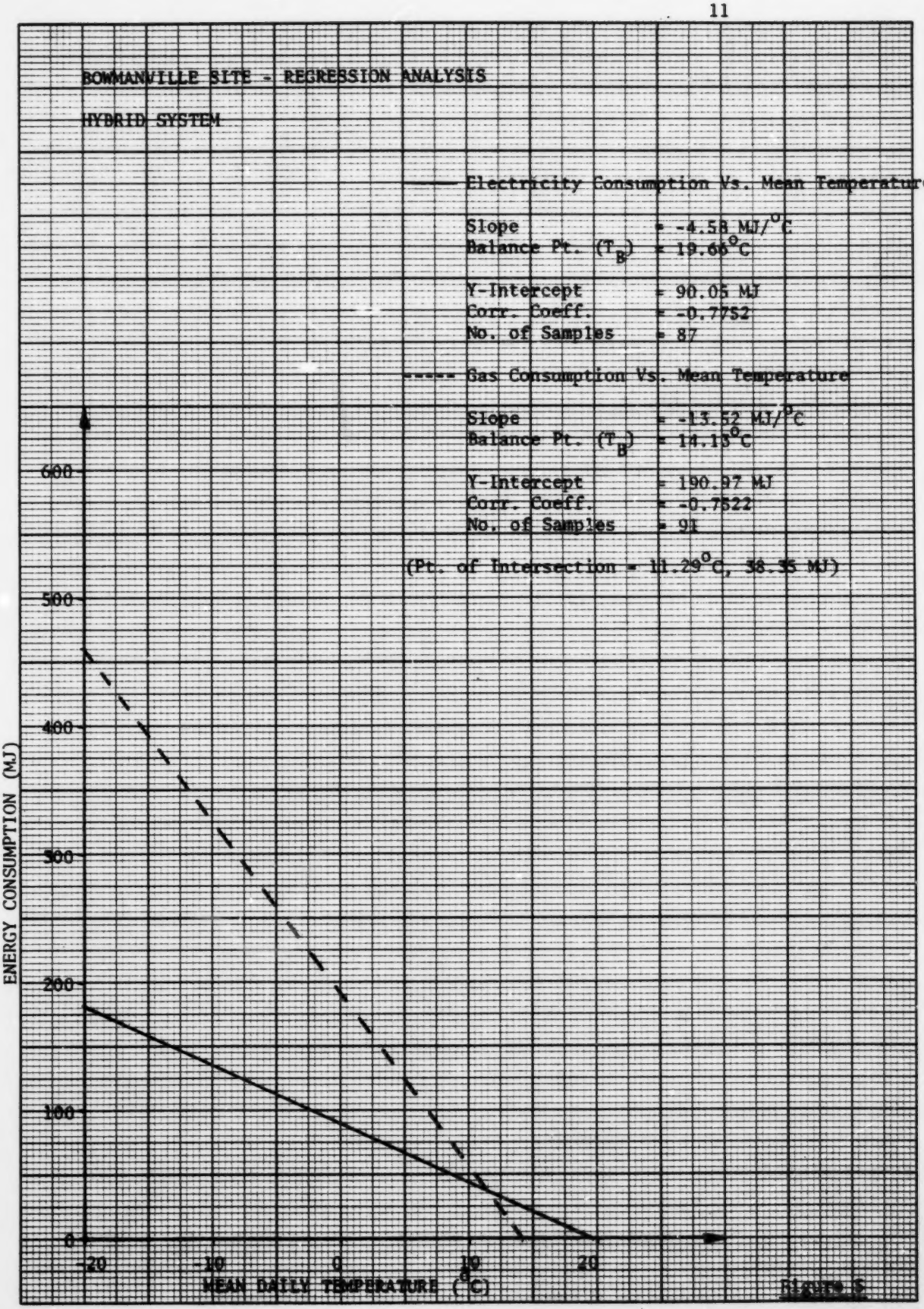

BOWMANVILLE SITE - REGRESSION ANALYSIS
HYBRID SYSTEM
—— Electricity Consumption Vs. Mean Temperature
Slope = -4.58 MJ/°C
Balance Pt. (T_B) = 19.66°C
Y-Intercept = 90.05 MJ
Corr. Coeff. = -0.7752
No. of Samples = 87
----- Gas Consumption Vs. Mean Temperature
Slope = -13.52 MJ/°C
Balance Pt. (T_B) = 14.13°C
Y-Intercept = 190.97 MJ
Corr. Coeff. = -0.7522
No. of Samples = 91
(Pt. of Intersection = 11.29°C, 38.35 MJ)
ENERGY CONSUMPTION (MJ)
600
500
400
300
200
100
0
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

Figure 5

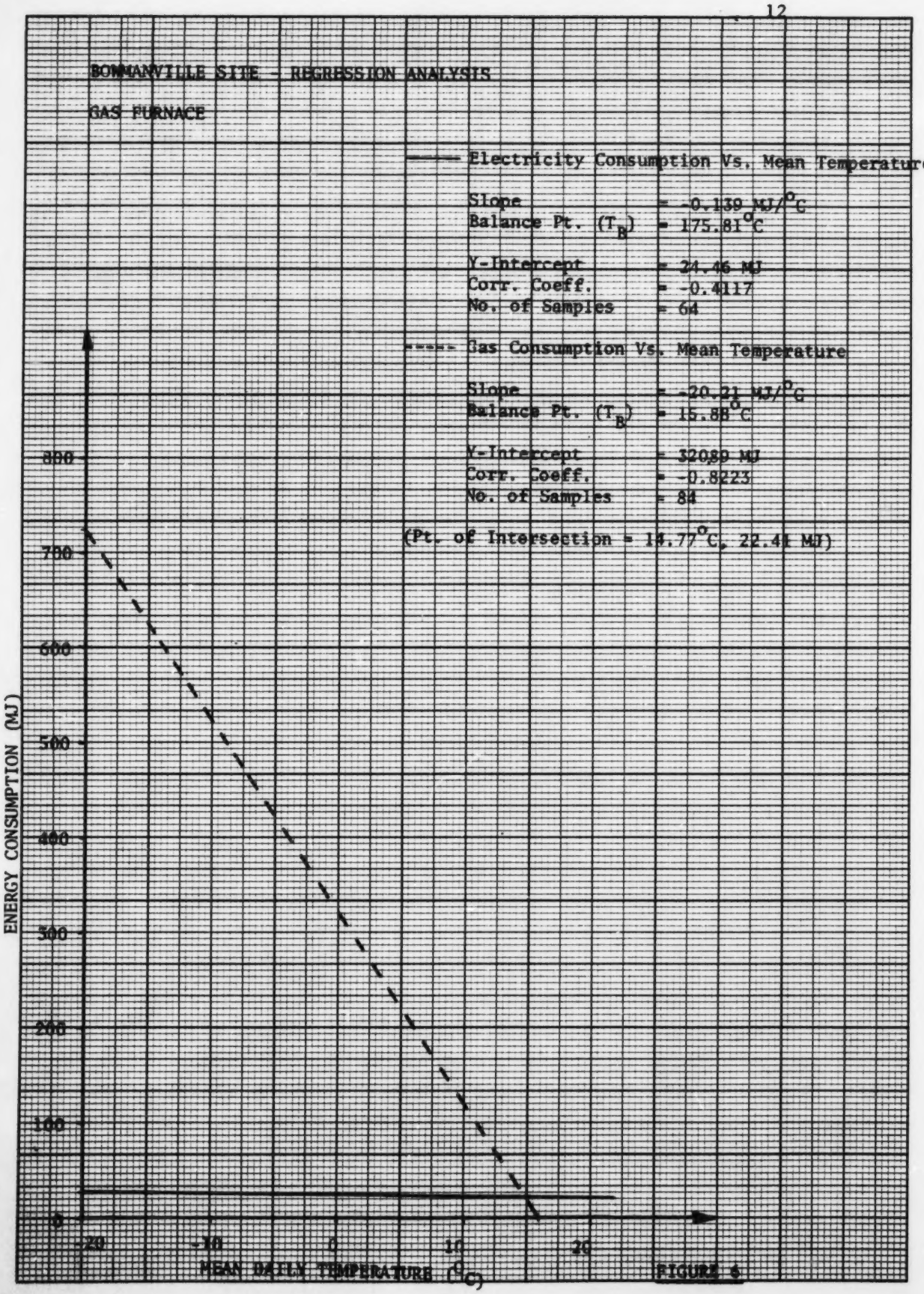

BOWMANVILLE SITE - REGRESSION ANALYSIS
GAS FURNACE
——— Electricity Consumption Vs. Mean Temperature
Slope = -0.139 MJ/°C
Balance Pt. (T_B) = 175.81°C
Y-Intercept = 24.46 MJ
Corr. Coeff. = -0.4117
No. of Samples = 64
----- Gas Consumption Vs. Mean Temperature
Slope = -20.21 MJ/°C
Balance Pt. (T_B) = 15.88°C
Y-Intercept = 32089 MJ
Corr. Coeff. = -0.8223
No. of Samples = 84
(Pt. of Intersection = 14.77°C, 22.41 MJ)
ENERGY CONSUMPTION (MJ)
800
700
600
500
400
300
200
100
0
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 6

1982/1983 heating season would indicate a greater confidence in this figure than the figure of 11°C reached during the previous season.

Figure 7 shows a graph of the total site energy use from both systems. This graph indicates that the total site energy consumption for the hybrid heat pump under test is less than the total site energy consumption for the conventional standing pilot, noncondensing gas furnace and implies that the hybrid appliance is marginally more efficient, seasonally, than the monitor at site.

The actual operating cost for each appliance installed at the Bowmanville site during the individual operating periods over the 1982/1983 heating season, is $215 for the hybrid unit under test and $232 for the conventional unit. The hybrid unit operated for a period of 108 days and the conventional unit operated for 106 days during the period from October, 1982 to May, 1983.

The total cost for the energy required to maintain a satisfactory comfort level in this residence over the total period of the test with both units operating on alternate days is $447. The monthly analysis of these costs is shown in Table 2.

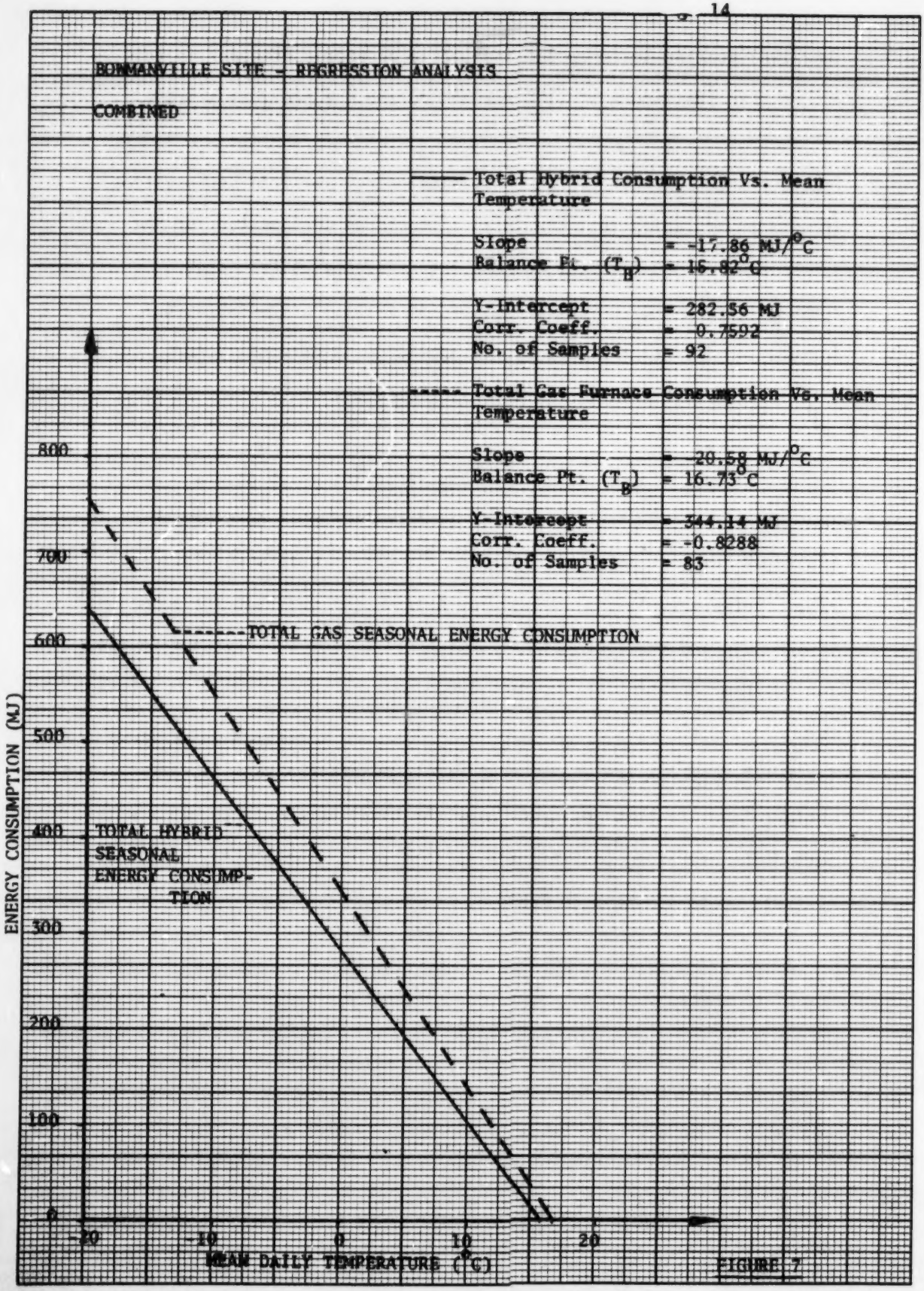

BONNANVILLE SITE - REGRESSION ANALYSIS
COMBINED
Total Hybrid Consumption Vs. Mean Temperature
Slope = -17.86 MJ/°C
Balance Pt. (T_B) = 16.82°C
Y-Intercept = 282.56 MJ
Corr. Coeff. = 0.7592
No. of Samples = 92
Total Gas Furnace Consumption Vs. Mean Temperature
Slope = -20.58 MJ/°C
Balance Pt. (T_B) = 16.73°C
Y-Intercept = 344.14 MJ
Corr. Coeff. = -0.8288
No. of Samples = 83
TOTAL GAS SEASONAL ENERGY CONSUMPTION
TOTAL HYBRID SEASONAL ENERGY CONSUMPTION
ENERGY CONSUMPTION (MJ)
800
700
600
500
400
300
200
100
0
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 7

SUMMARY OF 1982/1983 ACTUAL HEATING COSTS

TABLE 2

BOWMANVILLE SITE

Month	Hybrid System			Gas Furnace			Combined Monthly Totals ($)
	Electricity Cost ($)	Gas Cost ($)	Subtotal ($)	Electricity Cost ($)	Gas Cost ($)	Sub-total ($)	
October	6.20	3.23	9.43	1.68	3.87	5.55	14.98
November	13.79	9.66	23.45	6.89	19.97	26.86	50.31
December	20.45	19.33	39.78	7.24	28.99	36.23	76.01
January	22.06	23.20	45.26	10.65	47.66	58.31	103.57
February	19.26	19.33	38.59	7.81	30.27	38.08	76.67
March	15.63	13.53	29.16	8.23	25.13	33.36	62.52
April	14.75	7.73	22.48	7.78	15.46	23.24	45.72
May	5.52	1.30	6.82	4.56	5.80	10.36	17.18
Total	117.66	97.31	214.97	54.84	177.15	231.99	446.96

RATES: Gas - 22.7¢/m^3

Electricity - 3.83¢/kW·h

To arrive at a seasonal cost for the 1982/1983 heating season for each appliance, had it operated on its own throughout all of the season, the real time actual data gathered from each appliance and recorded on Figures 5 and 6 is applied to the actual daily mean, site gathered, temperatures for each month from September, 1982, to May, 1983, and computed to give the consumptions. The appropriate gas and electric rates are applied to these computed consumptions to arrive at a seasonal cost for each appliance. These computations show that, had the hybrid system operated for all of the 1982/1983 heating season on its own, the cost to the customer would be $398, whereas if the conventional gas furnace had operated on its own over the 1982/1983 heating season, the cost would have been $435, to give an indicated reduction in operating costs of $37.15 or 8.5% for the hybrid system. This analysis is shown in Table 3.

In order to arrive at an average or typical seasonal energy consumption and cost, the actual site data was applied against the daily average temperature for each day of the month for a typical heating year, using the 30-yr daily average temperatures recorded at Malton airport. In this typical heating year the energy cost for the hybrid unit would be $465, and for the conventional gas furnace $492, for a cost saving of $27 or 5.5%. The reduction in the cost can be rationalized because the 1982/1983 heating season was warmer than

1982/1983 COMPUTED SEASONAL HEATING COSTS *

TABLE 3

BOWMANVILLE SITE

Month	Mean Daily Temp. (°C)	Consumption/Month				Cost/Month				Savings ($)
		Hybrid System		Gas Furnace		Hybrid System		Gas Furnace		
		Electricity (kW·h)	Gas (m^3)	Electricity (kW·h)	Gas (m^3)	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)	
September	14.9	197.1	9.4	144.1	40.1	7.55	2.13	5.52	9.10	4.94
October	9.6	397.7	51.5	199.2	120.8	15.23	11.69	7.63	27.42	8.13
November	5.4	544.4	95.0	197.6	170.6	20.85	21.56	7.57	38.73	3.89
December	2.2	687.7	133.9	208.0	229.8	26.34	30.40	7.97	52.16	3.39
January	-2.8	886.2	190.6	214.0	314.4	33.94	43.27	8.20	71.37	2.36
February	-3.1	811.2	175.2	193.6	288.6	31.07	39.77	7.42	65.51	2.09
March	2.4	682.6	132.5	207.8	227.6	26.14	30.08	7.96	51.66	3.40
April	7.0	483.3	77.6	195.6	144.6	18.51	17.62	7.49	32.82	4.18
May	10.7	342.1	37.9	191.4	84.3	13.10	8.60	7.33	19.14	4.77
Total		5 032.3	903.6	1 751.3	1 620.8	192.73	205.1	67.09	367.91	37.15

Total Computed Seasonal Cost Hybrid System $397.87
Total Computed Seasonal Cost Gas Furnace System $435.00
Annual Savings $ 37.15

* Consumptions computed from near daily temperatures and regression equations.
Rates: Gas - 22.7¢/m^3
Electric - 3.83¢/kW·h

normal and the hybrid heating system would operate longer in the more efficient heat pump mode. This analysis is shown in Table 4.

The costs analyzed against Toronto climate normals gathered over the past 30 years at Malton are very similar to those 1981/1982 computed seasonal heating costs, which shows consistency and indicates confidence in the results from this site.

4.2 Willowdale

The test site at Willowdale is altered considerably from the arrangement analyzed during the 1981/1982 heating season, in which the hybrid system was paralleled to a conventional oil furnace.

This season, the hybrid unit is being compared to an electric plenum heater which is installed above the inside A-coil of the hybrid unit, and the hybrid system blower unit is utilized to distribute the warm air through the residence, regardless of whether the heat is provided by the plenum heater or the hybrid heat pump. This arrangement allows the hybrid heat pump to be compared to a hard reference, which will give an indication of the seasonal efficiency, as the hard reference plenum heater can be assumed to be 100% efficient at site. The physical arrangement of the modified test site is shown in Figure 8. The plenum heater fitted neatly into the 90-deg bend above the A-coil and it operated well over the season. The plenum heater consists of

30-YEAR AVERAGE SEASONAL HEATING COSTS *

TABLE 4

BOWMANVILLE SITE

Month	Mean Monthly Temp. (From 30-Yr. Daily)** (°C)	Consumption/Month				Cost/Month***				Savings ($)
		Hybrid System		Gas Furnace		Hybrid System		Gas Furnace		
		Electricity (kW·h)	Gas (m^3)	Electricity (kW·h)	Gas (m^3)	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)	
September	15.5	158.9	3.1	106.3	16.9	6.09	0.70	4.07	3.84	1.12
October	9.3	408.7	54.3	195.5	110.7	15.65	12.33	7.49	25.13	4.64
November	3.3	625.4	118.2	200.0	205.2	23.95	26.83	7.66	46.58	3.46
December	-3.5	913.5	195.8	214.8	326.1	34.99	44.45	8.23	74.02	2.81
January	-6.7	1 039.4	234.3	218.6	379.8	39.81	53.19	8.37	86.22	1.59
February	-6.1	916.3	205.3	196.8	333.5	35.09	46.60	7.54	75.70	1.55
March	-1.0	813.6	169.9	211.8	283.4	31.16	38.57	8.11	64.33	2.71
April	6.2	513.8	86.3	196.7	157.6	19.68	19.59	7.53	35.78	4.04
May	12.3	290.3	21.9	196.0	60.2	11.12	4.97	7.51	13.66	5.08
Total		5 679.9	1 089.1	1 736.5	1 873.4	217.54	247.23	66.51	425.26	27.00

Total Computed 30-year Seasonal Cost Hybrid System $404.77
Total Computed 30-year Seasonal Cost Gas Furnace System $491.77
Annual Savings $ 27.00

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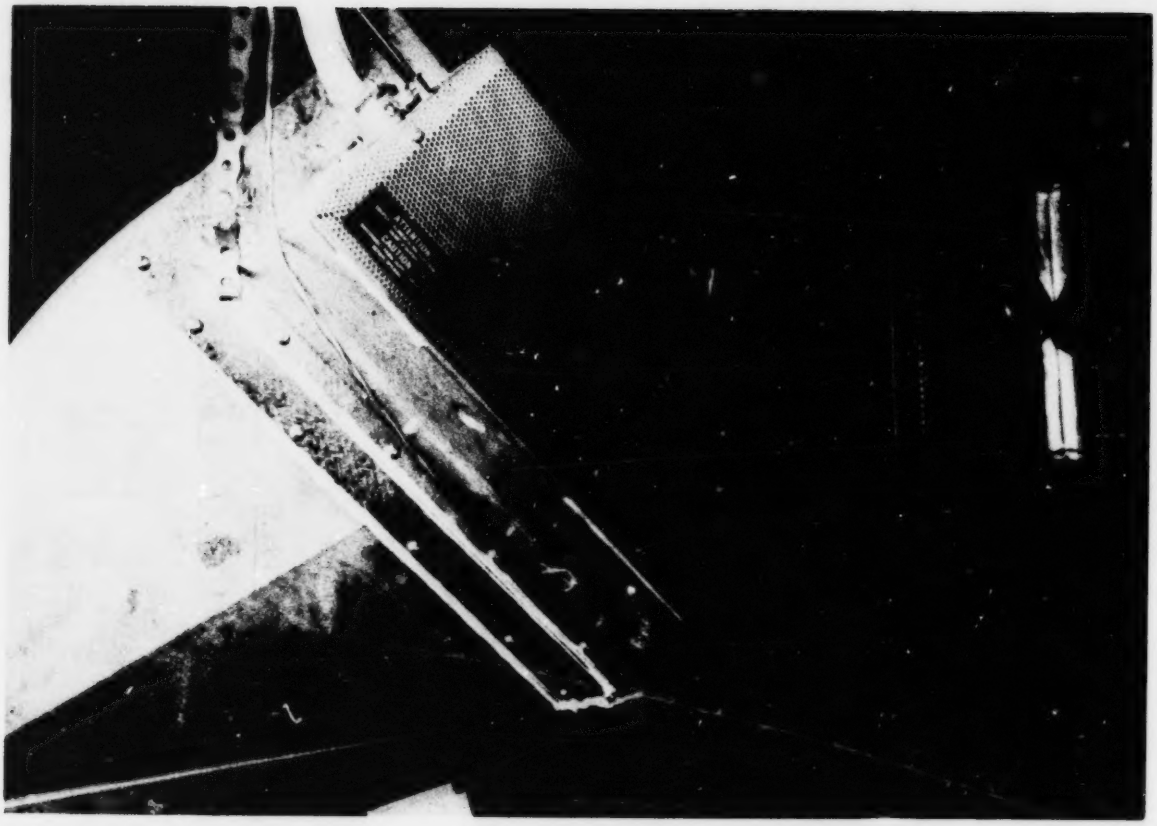
* Using least squares regression determined from 1982-1983 heating season data.
** Temperatures for Toronto International Airport 1951-1980.
*** Rates: Gas - 22.7¢/m^3
Electric - 3.83¢/kW·h



PLENUM HEATER INSTALLED IN DUCT

WILLOWDALE

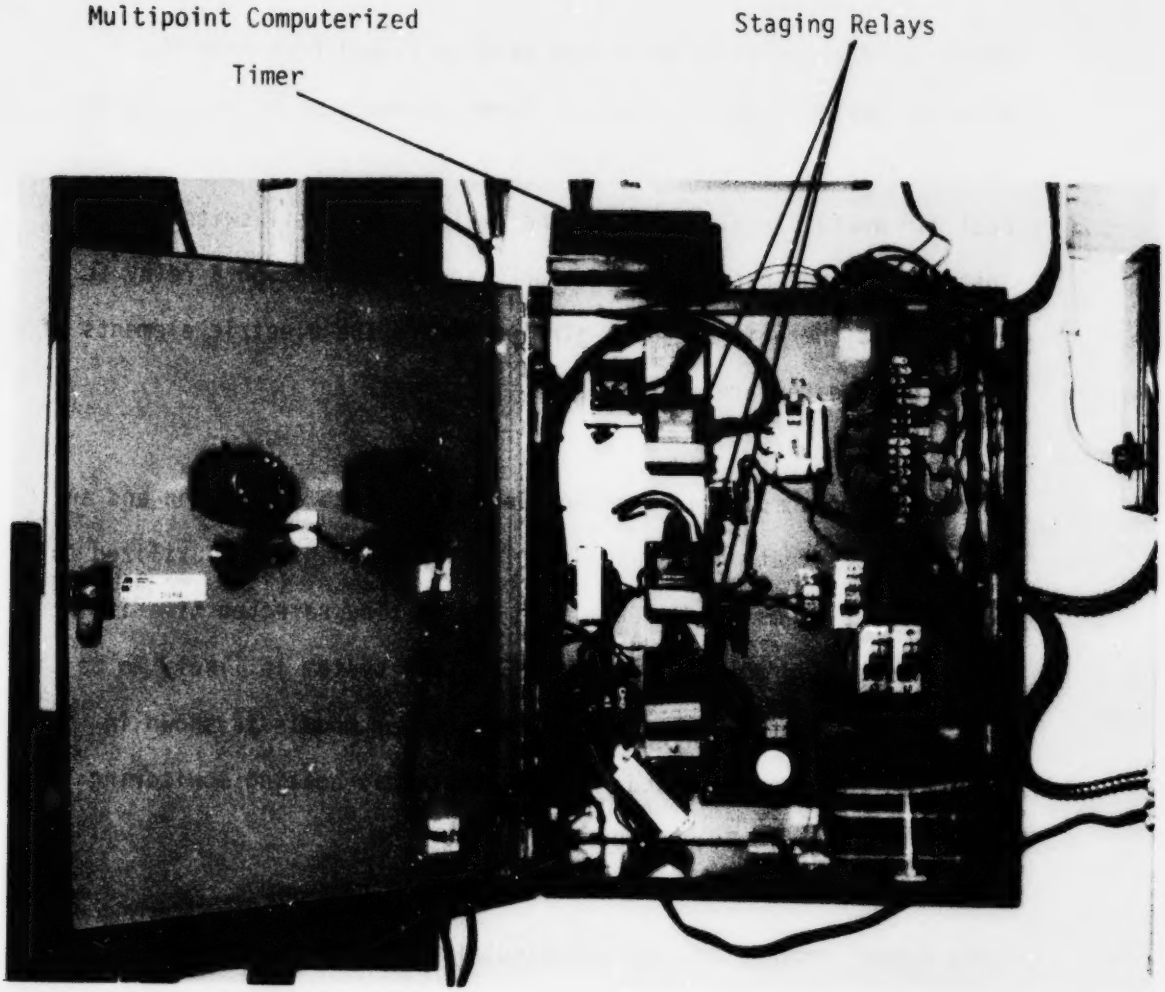
FIGURE 8

three, 5-kW elements in which the staging is modified from the original design in order that all three elements would be energized sequentially but almost simultaneously, to avoid a long period when cool air would circulate around the dwelling. A sail switch is installed in the return air ductwork, and wired through a relay to ensure that there is adequate airflow before the electric elements of the plenum heater are energized.

This neat and compact arrangement lends itself to automation and an automatic alternate day change-over control mechanism is utilized to change the systems at a preset time daily. The selected time is 1400 h as during this period of the day the system is likely to be cycling the least. The automatic change-over module is shown in Figure 9. The complete modified alternate day heating monitoring system is shown in Figure 10.

This system records the gas and electric energy used by the hybrid heat pump and the electric energy consumed by the plenum heater through the use of pulse producing gas and electric meters. The pulses are recorded every 15 minutes and transferred to a monthly tape on a Westinghouse tape recorder. The two electric meters and the tape recorder can be seen in Figure 10.

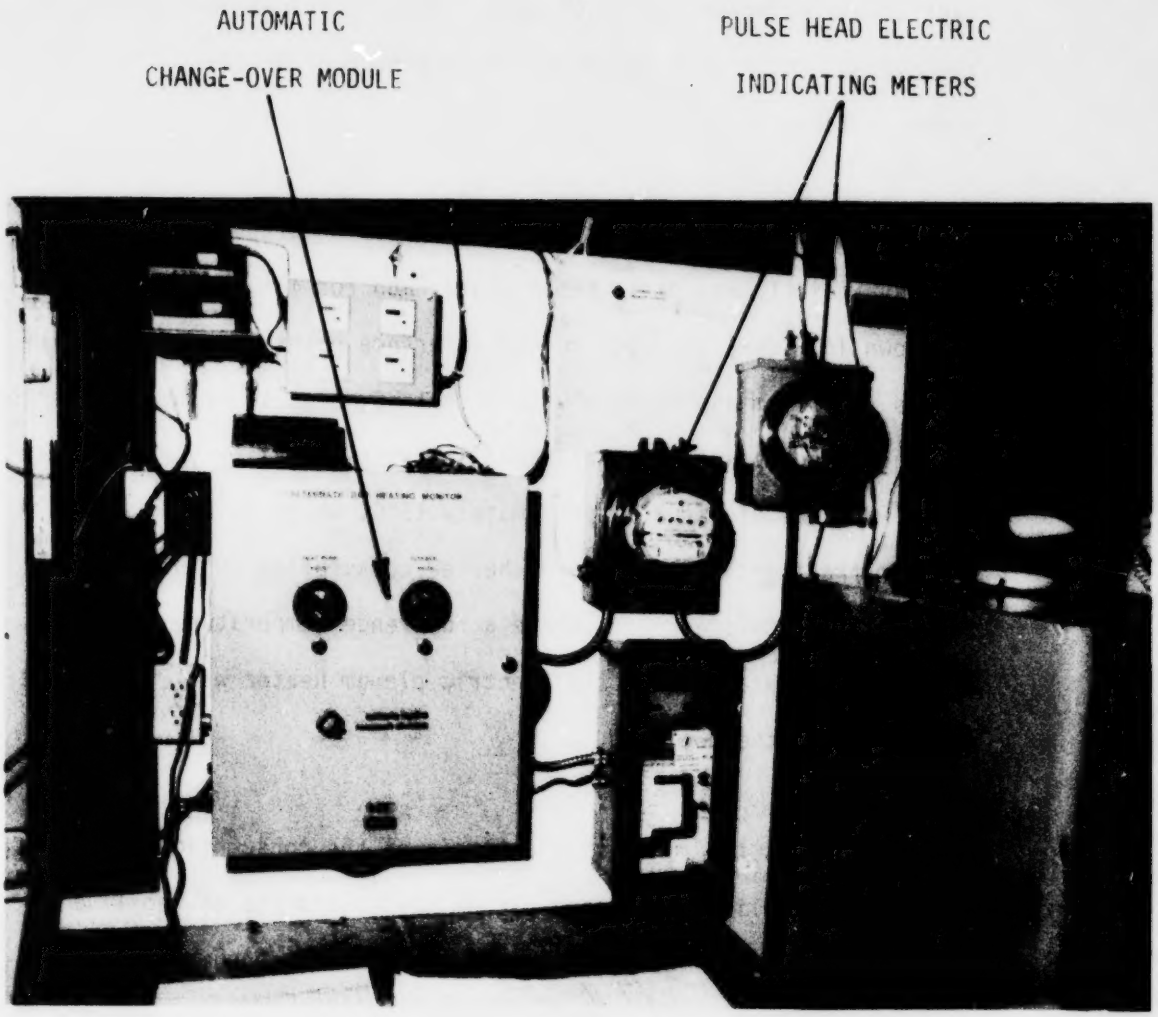
The data recorded manually at site are treated in a similar manner to that recorded at Bowmanville. The actual seasonal, alternate day eiectrical and gas consumptions for the hybrid system under test at Willowdale is 2 707 kW·h of electricity and 678 m^3 of natural gas



AUTOMATIC ALTERNATE DAY CHANGE-OVER MECHANISM

CONSTRUCTED BY ONTARIO HYDRO RESEARCH DIVISION

FIGURE 9



AUTOMATIC ALTERNATE DAY

MONITORING AND RECORDING SYSTEM

FIGURE 10

over an operating period of 88 days. The electrical consumption of the plenum heater is 8 218 kW·h over a period of 87 days. This is shown in Table 5.

These data are used to construct the regression graphs of consumption per day against mean daily temperature, and for the hybrid system this is shown in Figure 11. Again, the reference point intercepts on the x-axis vary from approximately 12°C to 14°C, because of the regression for each consumption being assumed linear. In reality the reference point would be higher at approximately 15°C, which is acceptable. A similar treatment for the plenum heater consumption is shown in Figure 12 and this analysis shows a reference temperature of 15°C, which is accurate because the electric plenum heater will follow the load line for the dwelling.

Figure 13 shows the regression analysis of the consumption of both systems, the solid line is the plenum heater and the dotted line represents the total combined (gas and electric) consumption for the heat pump unit.

The actual energy consumptions gathered for the site (Table 5), when multiplied by the appropriate tail-end energy rates, produce actual cost figure for the energy consumption used by both appliances individually.

SUMMARY OF 1982/1983 ACTUAL HEATING CONSUMPTION

TABLE 5

WILLOWDALE SITE

Month	Hybrid System			Plenum Heater	
	Electricity Consumption (kW·h)	Gas Consumption (m^3)	No. of Days Operating	Electricity Consumption (kW·h)	No. of Days Operating
November	281	62.3	12	834	12
December	483	135.0	16	1 492	15
January	621	173.7	15	2 115	16
February	553	138.8	14	1 663	14
March	454	104.8	16	1 277	15
April	315	65.2	15	837	15
Total	2 707	677.8	88	8 218	87

NOTE

Comparing the total kilowatt energy consumptions for each of the systems, hybrid and plenum heater the hybrid system used 15.45% more energy than the plenum heater. Assuming the plenum heater to be 100% efficient at site, the hybrid system at site would have a seasonal efficiency of 84.55%.

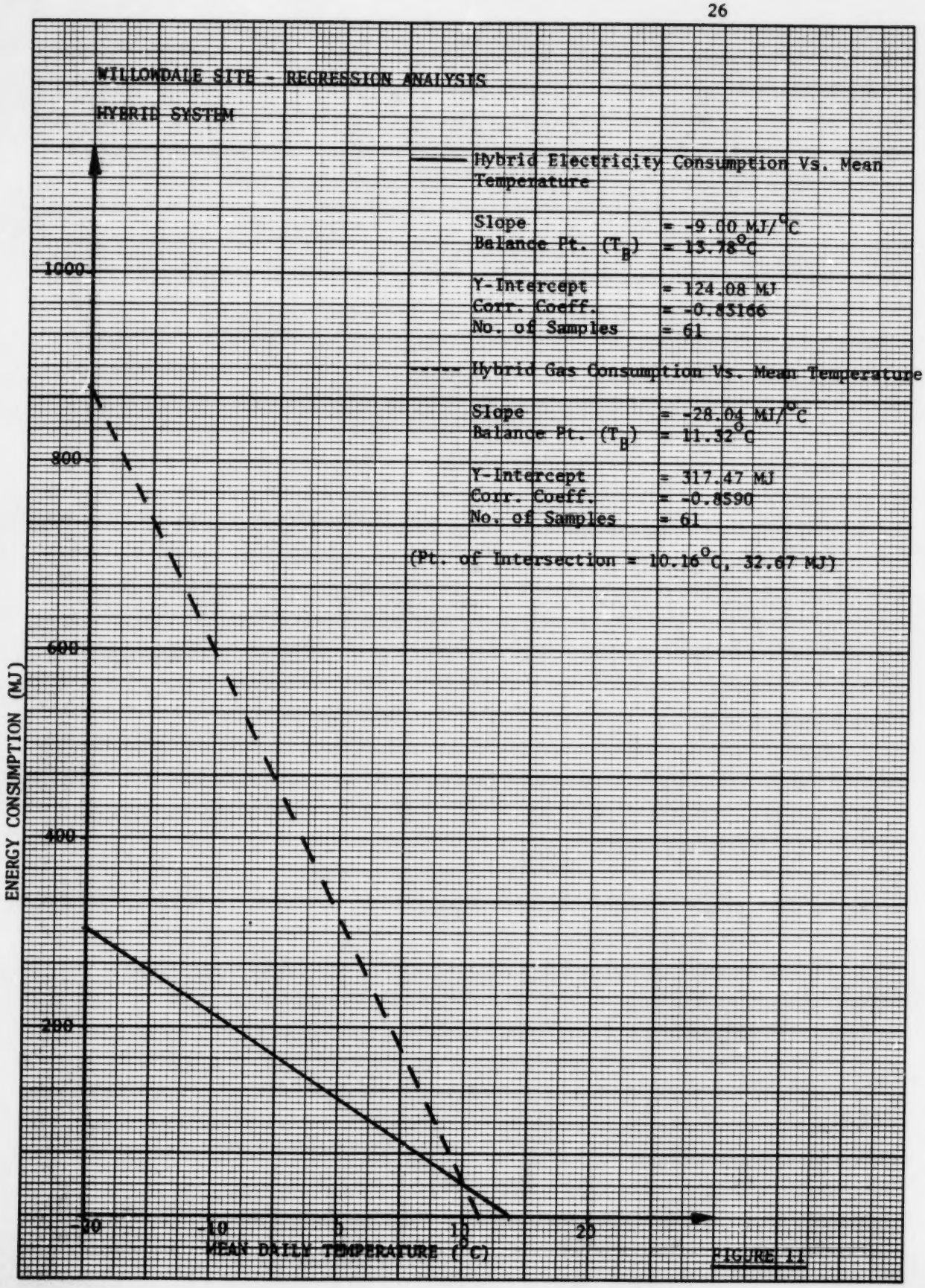

MILLONDALE SITE - REGRESSION ANALYSES
HYBRID SYSTEM
Hybrid Electricity Consumption Vs. Mean Temperature
Slope = -9.00 MJ/°C
Balance Pt. (T_B) = 13.78°C
Y-Intercept = 124.08 MJ
Corr. Coeff. = -0.83166
No. of Samples = 61
Hybrid Gas Consumption Vs. Mean Temperature
Slope = -28.04 MJ/°C
Balance Pt. (T_B) = 11.32°C
Y-Intercept = 317.47 MJ
Corr. Coeff. = -0.8590
No. of Samples = 61
(Pt. of Intersection = 10.16°C, 32.67 MJ)
ENERGY CONSUMPTION (MJ)
1000
800
600
400
200
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 11

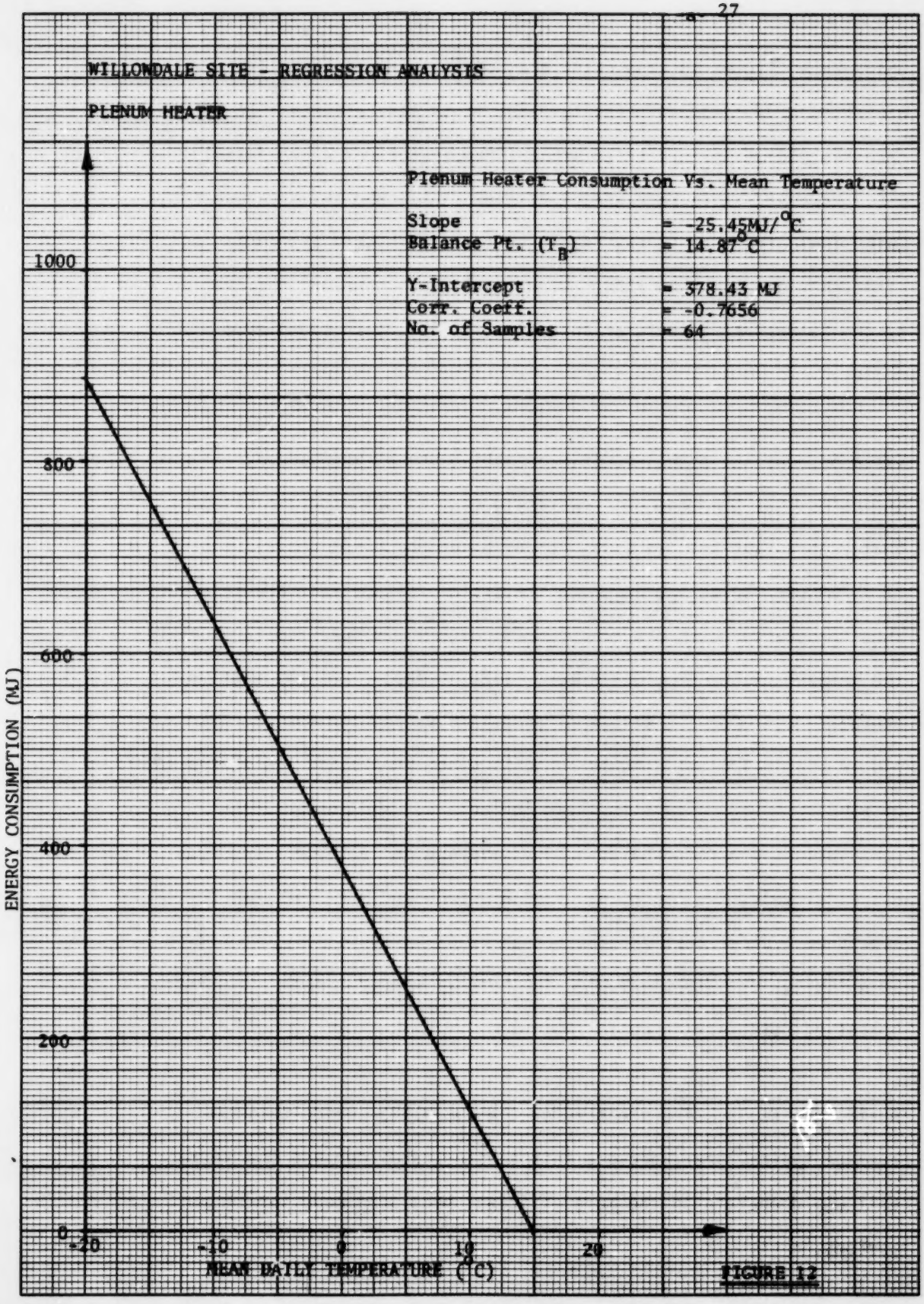

WILLOWDALE SITE - REGRESSION ANALYSIS
PLENUM HEATER
Plenum Heater Consumption Vs. Mean Temperature
Slope = -25.45MJ/°C
Balance Pt. (T_B) = 14.87°C
Y-Intercept = 378.43 MJ
Corr. Coeff. = -0.7656
No. of Samples = 64
ENERGY CONSUMPTION (MJ)
1000
800
600
400
200
0
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 12

This graph, Figure 13, indicates that when the hybrid unit is operating as a condensing gas furnace, it is less efficient at site than the plenum heater, to an ambient temperature of approximately 6°C. However, it is more efficient than the plenum heater above 6°C, which indicates that in the heat-pump mode the hybrid system has an efficiency greater than 100%. Over the season, however, the hybrid system is less efficient, at approximately 85%, than the plenum heater.

Table 6 shows the actual monthly breakdown which, when added, indicates that the test unit operating cost is $258 and the plenum heater operating cost is $315, for an annual combined operating cost of $573 over the period in which the system consumptions are recorded. When the energy costs are computed for each individual appliance over the heating season from September, 1982, to May, 1983, the total operating cost for the test appliance is $593 and for the electric plenum heater $761, giving an annual saving, when using the heat pump, of $168.00 or 22%. This is shown in Table 7. When these actual consumptions are referred to a 30-yr average daily temperature base or a typical year, the operating costs are $685 and $864 per year for hybrid unit under test and the plenum heater respectively, resulting in a savings of $179 or 20.6%. The monthly energy consumptions and operating costs are shown in Table 8.

Again, the savings are greater for the 1982/1983 season than the average typical year, because this season was milder and the hybrid unit would operate in the more efficient heat pump mode for longer periods.

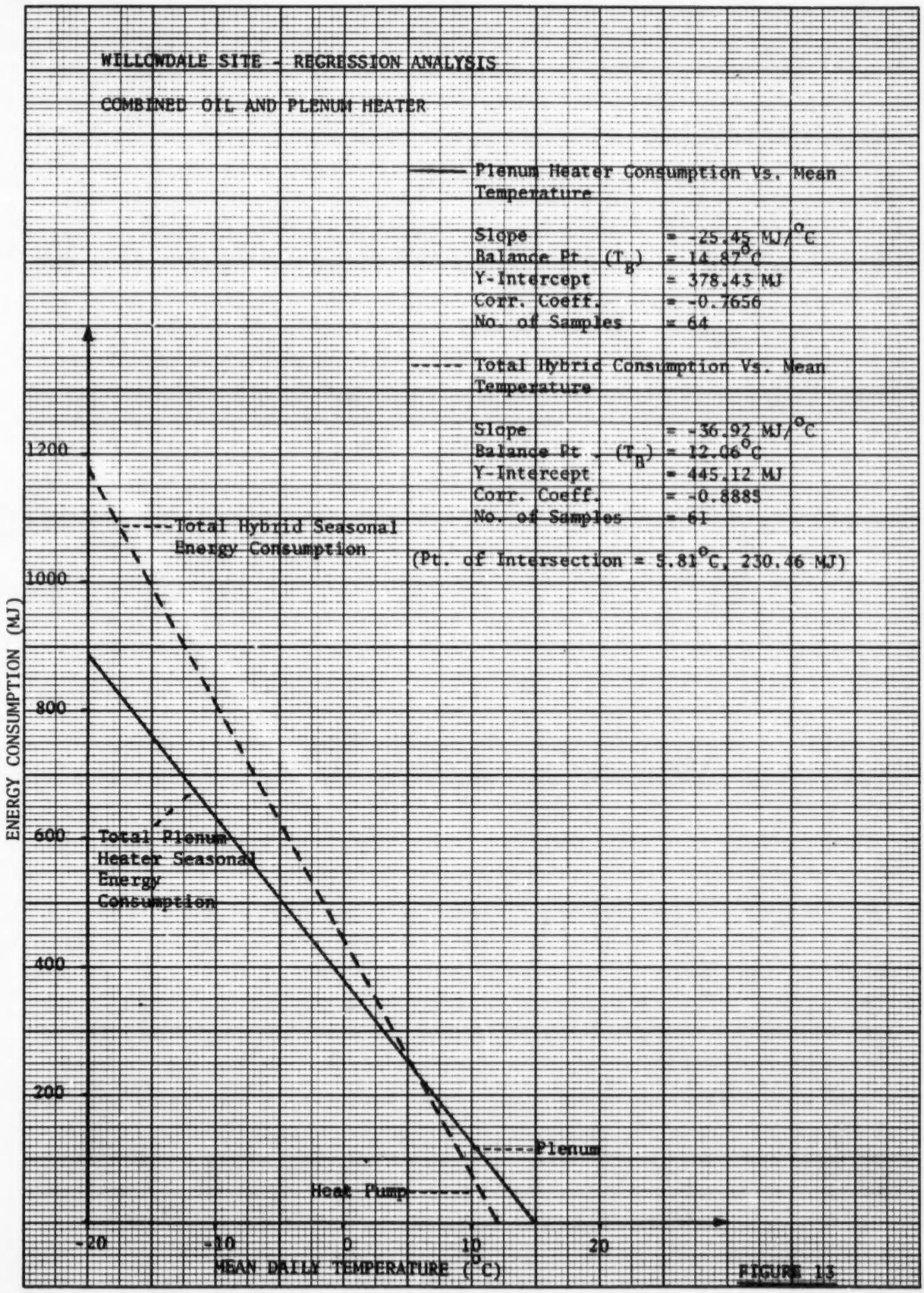

WILLOWDALE SITE - REGRESSION ANALYSIS
COMBINED OIL AND PLENUM HEATER
——— Plenum Heater Consumption Vs. Mean Temperature
Slope = -25.45 MJ/°C
Balance Pt. (T_B) = 14.87°C
Y-Intercept = 378.43 MJ
Corr. Coeff. = -0.7656
No. of Samples = 64
----- Total Hybrid Consumption Vs. Mean Temperature
Slope = -36.92 MJ/°C
Balance Pt. (T_B) = 12.06°C
Y-Intercept = 445.12 MJ
Corr. Coeff. = -0.8885
No. of Samples = 61
(Pt. of Intersection = 5.81°C, 230.46 MJ)
-----Total Hybrid Seasonal Energy Consumption
Total Plenum Heater Seasonal Energy Consumption
-----Plenum Heat Pump
ENERGY CONSUMPTION (MJ)
1200
1000
800
600
400
200
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 13

SUMMARY OF 1982/1983 ACTUAL HEATING COSTS *

TABLE 6

WILLOWDALE SITE

Month	Hybrid System			Plenum Heater
	Electricity Cost ($)	Gas Cost ($)	Combined Monthly Cost ($)	Electricity Cost ($)
November	10.76	14.14	24.90	31.94
December	18.50	30.64	49.14	57.14
January	23.78	39.43	63.21	81.00
February	21.18	31.51	52.69	63.69
March	17.39	23.79	41.18	48.91
April	12.06	14.80	26.86	32.06
Total			257.98	314.74

* Costs calculated using rates of 22.7¢/m³ for gas and 3.83¢/kW·h for electricity.

1982/1983 COMPUTED SEASONAL HEATING COSTS *

TABLE 7

WILLOWDALE SITE

Month	Mean Daily Temp. (°C)	Consumption/Month			Cost/Month		
		Hybrid System		Plenum Heater	Hybrid System		Plenum Heater
		Electricity (kW·h)	Gas (m^3)	Electricity (kW·h)	Electricity ($)	Gas ($)	Electricity ($)
September	14.9	53.2	4.1	253.5	2.04	0.93	9.71
October	9.6	333.8	63.2	1 178.0	12.78	14.35	45.12
November	5.4	611.8	140.6	1 979.1	23.43	31.92	75.80
December	2.2	961.3	246.0	2 987.3	36.82	55.84	114.41
January	-2.8	1 321.3	356.0	4 016.7	50.61	80.81	153.84
February	-3.1	1 112.6	296.6	3 397.7	42.61	67.33	130.13
March	2.4	946.7	242.1	2 938.0	36.26	54.96	112.52
April	7.0	641.7	150.1	2 064.9	24.58	34.07	79.09
May	10.7	299.7	54.2	1 058.8	11.48	12.30	40.55
Total		6 282.1	1 552.9	19 874.0	240.61	352.51	761.17

Total Computed Seasonal Cost Hybrid System	$593.12
Total Computed Seasonal Cost Plenum Heater System	$761.17
Annual Computed Savings	$168.05

* Consumption computed for mean daily temperatures and regression equations.
Rates: Gas - 22.7¢/m^3
Electricity - 3.83¢/kW·h

30-YEAR AVERAGE SEASONAL HEATING COSTS *

TABLE 8

WILLOWDALE SITE

Month	Mean Monthly Temp. (From 30-Yr. Daily)** (°C)	Consumption/Month			Cost/Month***			SAVINGS ($)
		Hybrid System		Plenum Heater	Hybrid System		Plenum Heater	
		Electricity (kW·h)	Gas (m^3)	Electricity (kW·h)	Electricity ($)	Gas ($)	Electricity ($)	
September	15.5	15.3	-	115.5	0.59	-	4.42	3.83
October	9.3	350.9	55.2	1 220.6	13.44	12.53	46.75	20.78
November	3.3	791.0	181.8	2 458.8	30.30	41.27	94.17	22.60
December	-3.5	1 342.6	346.1	4 026.1	51.42	78.56	154.20	24.22
January	-6.7	1 589.8	420.6	4 725.3	60.89	95.48	180.98	24.61
February	-6.1	1 391.9	366.6	4 143.4	53.31	83.22	158.69	22.16
March	-1.0	1 146.1	286.9	3 470.3	43.90	65.13	132.91	23.88
April	6.2	571.8	115.7	1 838.8	21.90	26.26	70.43	22.27
May	12.3	133.3	8.9	567.4	5.10	2.02	21.73	14.61
Total		7 332.7	1 781.8	22 666.2	280.85	404.47	864.28	178.96

Total Computed 30-year Seasonal Cost Hybrid System $685.32
Total Computed 30-year Seasonal Cost Plenum Heater System $864.28
Annual Savings $178.96

* Using least squares regression determined from 1982-1983 heating season data.
** Temperatures for Toronto International Airport 1951-1980.
*** Rates: Gas - 22.7¢/m^3
Electricity - 3.83¢/kW·h

rd3/da

The computed figures for the operating cost comparison with a conventional oil furnace during the 1981/1982 heating season are $1,118.73 for the oil furnace compared to the hybrid system annual operating cost of $754.49 for an annual saving of $364.94 or 32.62%.

When the data are referred to a 30-yr daily temperature for a typical year, the cost to operate the conventional oil furnace is $1009.74 and to operate the hybrid system the cost is $679.02 per year for an annual saving with respect to the hybrid system of $330.72 or 32.75%. This 30-yr data compilation is shown in Table 9.

Figure 14 shows the regression analyses graph of the oil furnace for the 1981/1982 heating season compared to the graph of the hard reference load line developed during the 1982/1983, from the plenum heater.

The comparison of the respective slopes of these lines gives an indication of the seasonal efficiency of the oil furnace. This computes to 64.3%.

For more detailed information on the 1981/1982 heating season oil comparison refer to the interim report ISBN-0-7743-81-981 published in February, 1983.

30-YEAR AVERAGE SEASONAL HEATING COSTS *

TABLE 9

WILLOWDALE SITE - OIL FURNACE AND PLENUM HEATER

Month	Mean Monthly Temp. (From 30-Yr. Daily** (°C)	Consumption/Month				Cost/Month***				Savings ($)
		Hybrid System		Oil Furnace		Hybrid System		Oil Furnace		
		Electricity (kW·h)	Gas (m^3)	Electricity (kW·h)	Oil (l)	Electricity ($)	Gas ($)	Electricity ($)	Oil ($)	
September	16.2	50	7	0	0	1.78	1.47	0	0	-3.25
October	10.3	453	107	93	165	16.08	22.47	3.30	48.35	13.10
November	3.8	867	210	150	359	30.78	44.10	5.33	105.19	35.64
December	-3.1	1365	334	248	589	48.46	70.14	8.80	172.58	62.78
January	-6.3	1582	388	310	691	56.16	81.48	11.01	202.46	75.83
February	-5.4	1374	337	252	598	48.78	70.77	8.95	175.21	64.61
March	-0.7	1202	293	217	513	42.67	61.53	7.70	150.31	53.81
April	6.6	682	164	120	273	24.21	34.44	4.26	79.99	25.60
May	12.8	283	65	31	86	10.05	13.65	1.10	25.20	2.60
Total		7858	1905	1421	3274	278.97	400.05	50.45	959.29	330.72

Total Computed 30-year Seasonal Cost of Hybrid System $ 679.02
Total Computed 30-year Seasonal Cost of Oil Furnace System $1009.74
Annual Savings $ 330.72

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* Using least squares regression determined from 1981-1982 heating season data.
** Temperatures for Toronto International Airport, 1951-1980.
*** Rates: Gas - 21¢/m^3
Oil - 29.3¢/l
Electricity - 3.55¢/kW·h

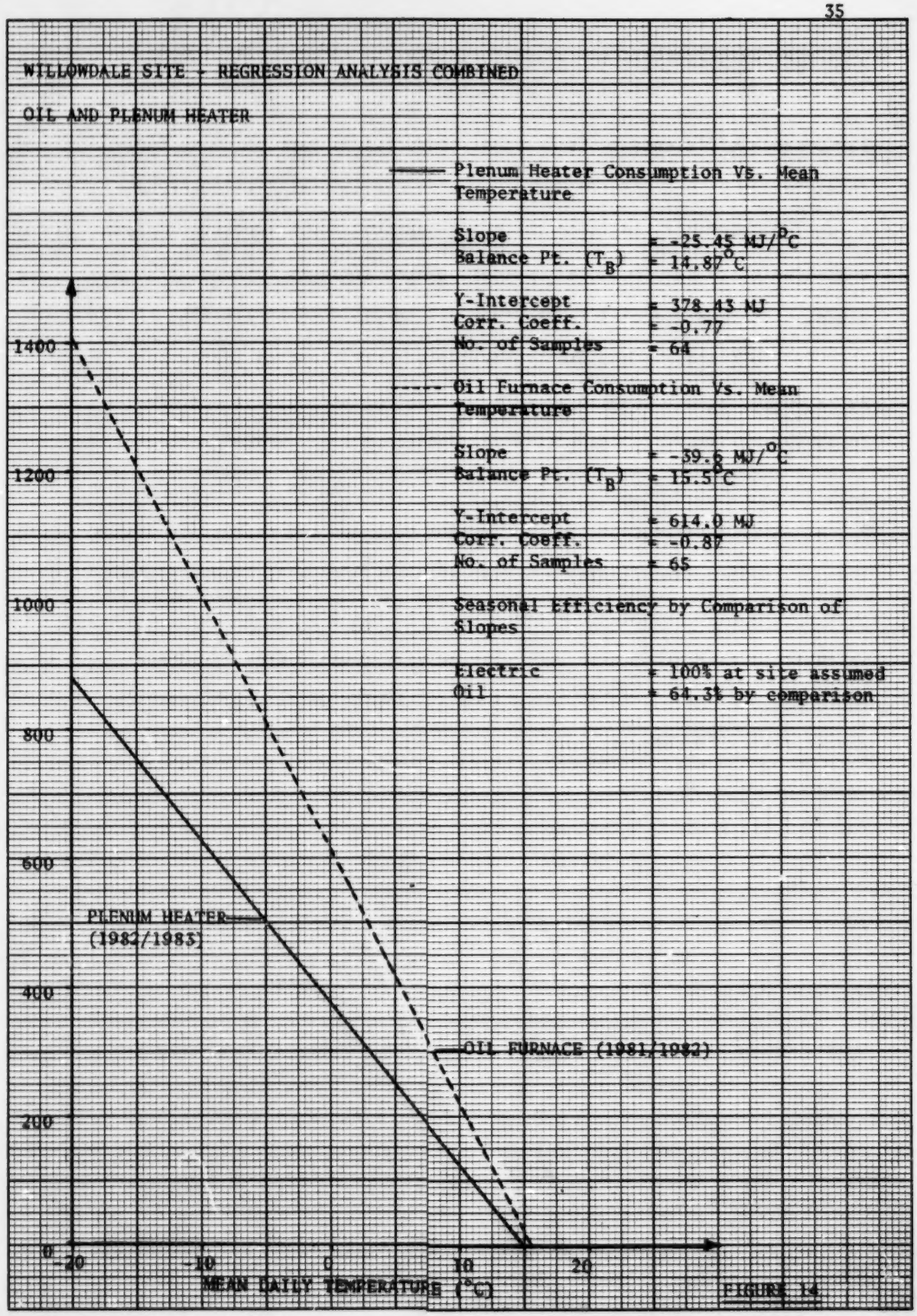
WILLOWDALE SITE - REGRESSION ANALYSIS COMBINED
OIL AND PLENUM HEATER
Plenum Heater Consumption Vs. Mean Temperature
Slope = -25.45 MJ/°C
Balance Pt. (T_B) = 14.87°C
Y-Intercept = 378.13 MJ
Corr. Coeff. = -0.77
No. of Samples = 64
Oil Furnace Consumption Vs. Mean Temperature
Slope = -39.6 MJ/°C
Balance Pt. (T_B) = 15.5°C
Y-Intercept = 614.0 MJ
Corr. Coeff. = -0.87
No. of Samples = 65
Seasonal Efficiency by Comparison of Slopes
Electric = 100% at site assumed
Oil = 64.3% by comparison
ENERGY CONSUMPTION (MJ)
1400
1200
1000
800
600
400
200
0
PLENUM HEATER (1982/1983)
OIL FURNACE (1981/1982)
-20
-10
0
10
20
MEAN DAILY TEMPERATURE (°C)

FIGURE 14

5.0 PERFORMANCE EFFICIENCY - HYBRID SYSTEM

Performance efficiency tests were not conducted as part of these field investigations, but Ontario Hydro Research Division at Kipling Avenue conducted laboratory tests on the space heating and cooling system, and concluded that when the novel device operated as a gas furnace, steady-state efficiencies ranged from 91% to 98%. When operating as a heat pump in the heating mode, the steady-state coefficient of performance averaged 2.1 at 8°C and 1.4 at -8°C. These coefficients of performance (COP) are considerably lower than the published figures for contemporary traditional heat pumps, which have COP's in the region of 3.0 at 8°C and 2.2 at -8°C. Analyses of the consumption data and the regression graphs tend to confirm this finding. Utilization efficiency is dependent, not only on the basic appliance characteristics, but also on the system to which it is connected, and these systems vary greatly from residence to residence. A conclusion drawn on a small sample, while representative, is not statistically significant.

6.0 SOUND MEASUREMENTS

One of the concerns with the external units of heat pumps is the level of noise generated by the outdoor fan or air mover. Recognizing this concern, sound level tests were conducted on the two hybrid heat pumps under test. The sound measurements were taken both indoors and outdoors using a Bruel and Kjaer Impulse Precision Sound Level Meter, Type 2209. The slow meter characteristic was used and the decibel readings were determined on the 'A' weighting network (dBA).

The readings for each site are shown in Tables 10 and 11 and the locations are shown in Figures 15 and 16.

The average sound level produced by the unit at Bowmanville is 64.0 dBA against a background of 35.0 dBA. The average sound level at Willowdale is 65.5 dBA against a background noise of 61.0 dBA. In effect, at this site there is virtually no increase in noise production at the external unit because of the ambient noise. The levels are lower than those noises recorded for most conventional heat pumps.

The internal noise generated by the internal fan unit averaged 57.0 dBA for the Bowmanville unit and 60.0 dBA for the Willowdale unit, which appears high for internal noise. At the Willowdale site the internal noise during the nocturnal hours is somewhat objectionable to the occupants.

Start-up noise, while not measured, is very noticeable at both sites.

TABLE 10

NOISE LEVEL TESTS - BOWMANVILLE

Location	Test Parameters	Noise Level During Unit Operation, dBA
1	outside - 1 m west of unit	66
2	outside - 2 m west of unit	63
3	outside - 3 m west of unit	60
4	outside - 1 m north of unit	67
5	outside - 2 m north of unit	63*
6	outside - 1 m east of unit	68
7	outside - 2 m east of unit	64
8	outside - 3 m east of unit	61
9	inside - 1 m north of unit	60
10	inside - 1 m west of unit	56*
11	inside - 1 m south of unit	56

Conditions: Tests were conducted in the morning. The day was a clear and breezy 23°C. The outside ambient noise level was 35 dBA with intermittent higher levels from traffic on Highway 401 (about 0.5 km to the south). The unit was installed 0.2 m from the north wall of the residence. The inside ambient noise level was 47 dBA with the furnace fan on constant low speed.

* Location of ambient noise level recordings.

TABLE 11

NOISE LEVEL TESTS - WILLOWDALE

Location	Test Parameters	Noise Level During Unit Operation, dBA
1	outside - 1 m east of unit	69
2	outside - 2 m east of unit	65
3	outside - 3 m east of unit	62
4	outside - 1 m south of unit	68
5	outside - 2 m south of unit	65
6	outside - 3 m south of unit	64*
7	inside - 1 m west of blower	59*
8	inside - 1 m south of blower	57

Conditions: Tests were conducted in the morning. The day was a clear and breezy 25°C. Wind in the leaves of numerous deciduous trees did not add to the ambient noise level of 61 dBA due to proximity of Highway 401. The highway is about 75 m to the north of the building. The unit was installed 0.7 m from the south wall of the residence. The inside ambient noise level was 32 dBA.

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* Location of ambient noise level recordings.

rd3/db

NOISE LEVEL TEST LOCATIONS

63 ROSER CRES., BOWMANVILLE

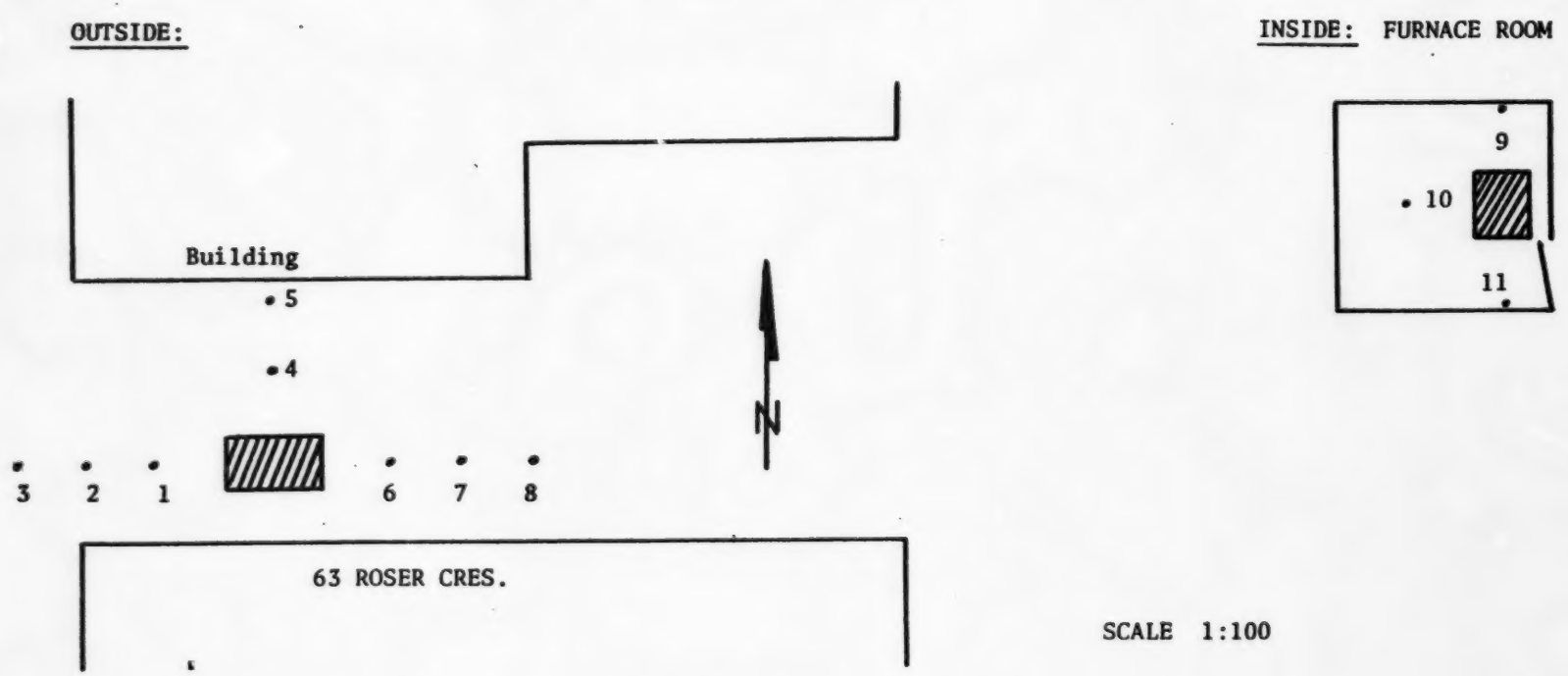
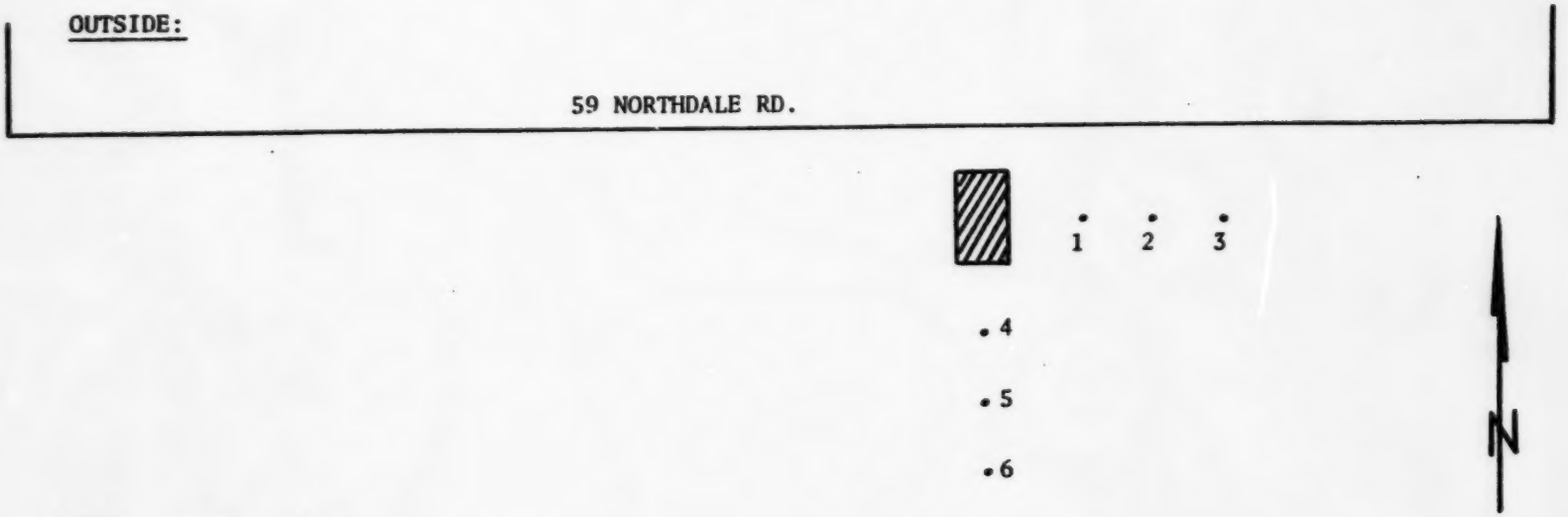


FIGURE 15

NOISE LEVEL TEST LOCATIONS

59 NORTHDALE RD., WILLOWDALE



(Further measurements were restricted by room design)

SCALE 1:100

FIGURE 16

7.0 COMMENTS ON FUNCTIONAL OPERATION

Both systems performed in a satisfactory manner over the 1982/1983 heating season, providing adequate thermal comfort for the owners of the test dwellings, however, the reduction in supply air temperature and the increase in velocity of the supply air is noticeable on startup. Indoor noise on startup is also noticeable.

There were no service calls of any nature at either site and during this second year of operation the reliability of both units is entirely satisfactory to the present time.

Overall, the data gathered during the 1982/1983 season show a good correlation and consistency with that gathered during the previous season with respect to 30-yr annualized costs for the operation of the hybrid systems. At both Bowmanville and Willowdale, the 30-yr annualized energy consumptions are very similar, as are the costs, considering the fuel cost increases. Climatic variables such as wind, humidity, solar gains, and regional differences in average heating season temperatures can often lead to differences in the measured savings for comparable tests but in this series there is remarkable similarity in the results, which increases the confidence level in the findings.

Visual examination of the outdoor fin coil unit revealed that there was no apparent deterioration of either the aluminum fins or copper tubes. An inductively coupled argon plasma scan of the condensate revealed no particular metal inclusions of copper, 0.72 mg/l, but fairly high amounts

of aluminum, 6.90 mg/l, and high levels of zinc, 13.00 mg/l. The fairly high aluminum level could indicate that there is some erosion of the aluminum fins by the condensate. The high zinc level would indicate that the condensate, which is collected in a galvanized tray located below the outdoor coil, is attacking the tray. Figure 17 shows the complete analysis.

It can be assumed that the erosion of the outdoor coil by the action of the acidic condensate is insignificant over the two seasons during which the systems have operated. The condensate collection tray and drain may be eroded over time if the zinc coating is penetrated by condensate activity.

INDUCTIVELY COUPLED ARGON

PLASMA SCAN OF CONDENSATES

Metal Elements	Amount of Metals in Condensate mg/l
Si	0.20
Al	6.90
Fe	0.10
Ca	2.80
Mg	0.48
Na	1.00
K	3.00
Tl	0.01
Mn	0.14
P	0.50
Ba	0.01
Cr	0.01
Zr	0.01
Cu	0.72
Ni	0.05
Ph	0.03
Zn	13.00
V	0.01
Sr	0.01
Co	0.01
Mo	0.02
Cd	0.01
Be	0.02
B	0.05

CONDENSATE ANALYSIS

FIGURE 17

8.0 CONCLUSIONS

1. Both of the hybrid systems performed in a satisfactory manner, maintaining an adequate comfort level at each site.

2. The hybrid system does not show any significant seasonal cost savings over a standing pilot gas furnace when each is related to 30-yr average weather data. The savings are $27 or 5.5%.

3. The hybrid system does show significant cost savings over a plenum heater. When related to 30-yr average weather, a saving of $179 or 20.6% is obtained, which is a lesser saving than that obtained over the conventional oil furnace.

4. The hybrid system shows significant cost savings over conventional oil furnace. When related to 30-yr average weather data the savings are $364.94 or 32.6%. (1981/1982 field analysis.)

5. Noise levels are acceptable from the outdoor units, but noise and air movement inside the dwellings are higher than conventional, forced warm-air systems.

6. No service or maintenance was performed on either of the systems during the 1982/1983 heating season, indicating seasonal reliability.

9.0 RECOMMENDATION

The field evaluations at Bowmanville and Willowdale should be terminated as consistent results have been obtained over a 2-yr period and these findings can be used with confidence.

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